

Rectifier Circuits

One important application of diodes is in the design of rectifier circuits. A diode rectifier forms the first stage of a dc power supply as shown in figure below. As we will see throughout the text, a dc power is required to bias all electronic circuits. The output voltage V_o will usually be in the range of 3 to 24V depending on the particular electronics application. Throughout the first part of this lesson we will analyze the various stages in the power supply circuit.

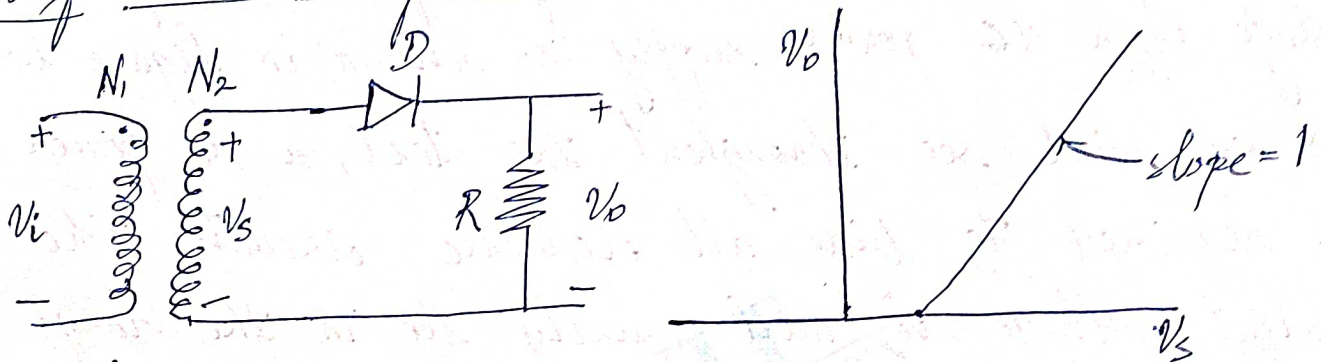


Diagram of an electronic power supply

Rectification is the process of converting an alternating (ac) voltage into one that is limited to one polarity. The diode is useful for this function because of its non linear characteristics; that is, current exists for

for one voltage polarity. Rectification is classified as half wave or full wave, with half wave being the simpler and full wave being more efficient.

Half wave rectification



The above figure shows a power transformer with a diode and resistor connected to the secondary of the transformer. We will use the piecewise linear approach in analyzing this circuit assuming that the diode forward resistance $r_f = 0$ when the diode is "on".

The input signal ~~is a~~ V_i is in general a 230V 50 Hz ac signal. Recall that the secondary voltage V_s and primary voltage V_i of an ideal transformer are related by

$$\frac{V_i}{V_s} = \frac{N_1}{N_2}$$

where N_1 and N_2 are the number of primary and secondary turns respectively. The ratio N_2/N_1 is called

The transformer turns ratio. The transformer turns ratio will be designed to provide a particular secondary voltage V_s , which is then a particular output voltage V_o .

In using the piecewise linear model of the diode, the first objective is to determine the linear region in which the diode is conducting.

1. Determine the input voltage condition such that a diode is conducting (on). Then ^{find} the output signal for this condition.
2. Determine the input voltage condition such that a diode is not conducting (off). Then find the output signal for this condition.

The second figure above shows the voltage transfer characteristics V_o versus V_s , for the circuit. For $V_s < V_r$ the diode is reverse biased, which means the current is zero. As long as $V_s < V_r$ the diode will be nonconducting, so the output voltage will remain zero. When $V_s > V_r$, the diode becomes forward biased and the current is induced in the circuit.

In this case we can write

$$i_D = \frac{V_S - V_T}{R}$$

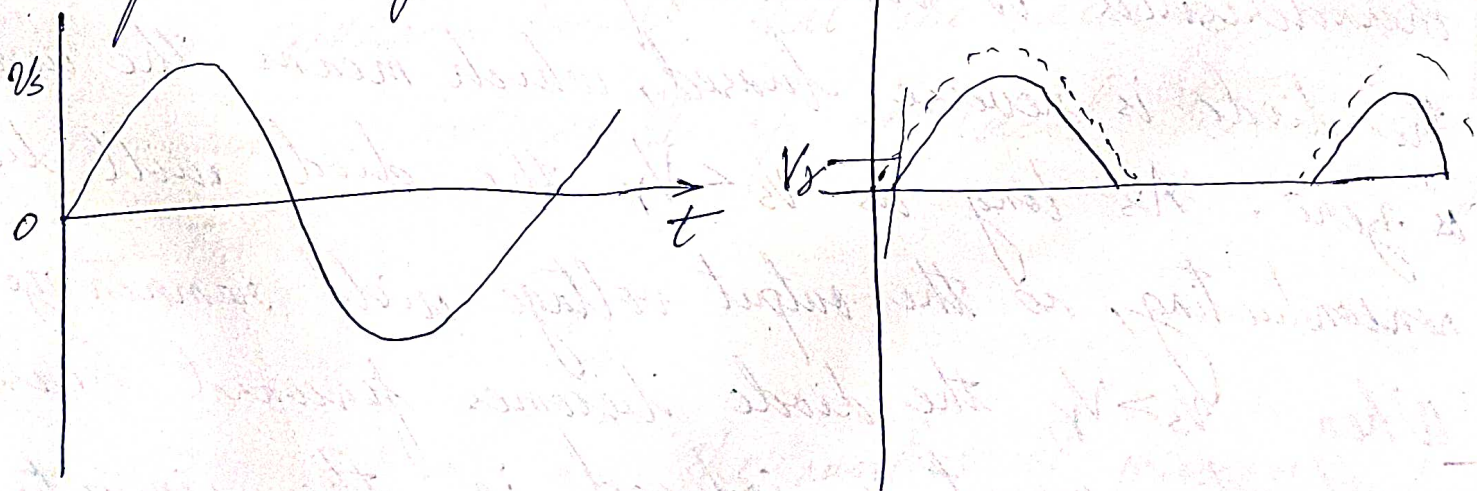
and

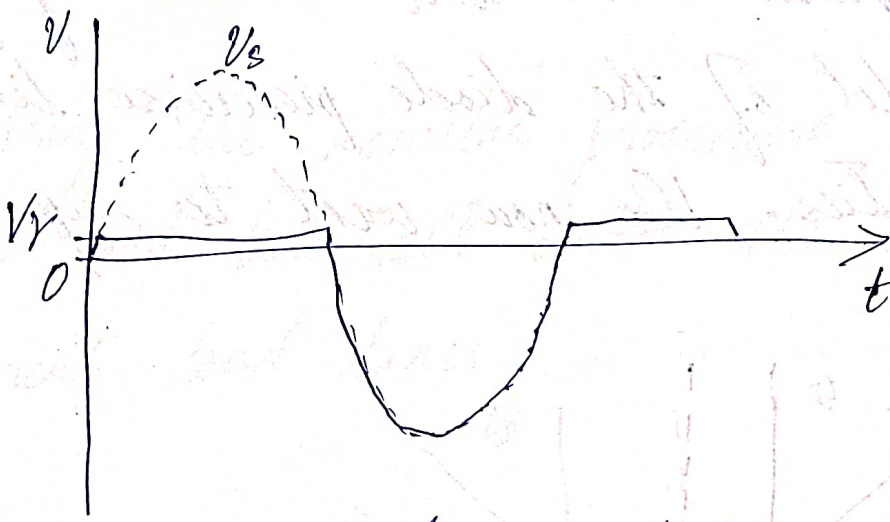
$$V_O = i_D R = V_S - V_T$$

For $V_S > V_T$ the slope of the transfer curve is 1. If V_S is a sinusoidal signal the output voltage can be found using the voltage transfer curve. For $V_S < V_T$ the output voltage is zero; for $V_S > V_T$ the output is given by

$$V_O = V_S - V_T$$

We can see that while the input signal V_S alternates polarity and has time average value of zero, the output voltage V_O is unidirectional and has an average value that is not zero. The input signal is therefore rectified.





When the diode is cut off and non conducting, no voltage drop occurs across the resistor R ; therefore the entire input signal voltage appears across the diode. Consequently the diode must be capable of handling the peak current in the forward direction and sustaining the largest peak inverse voltage (PIV) without breakdown. For the circuit shown above the value of PIV is equal to the peak value of V_s .

The load line concept can also help in visualising the operation of half wave rectifier. Summing voltages around the secondary loop of the circuit in the above figure yields:

$$V_s = V_D + i_D R$$

Full-Wave Rectification

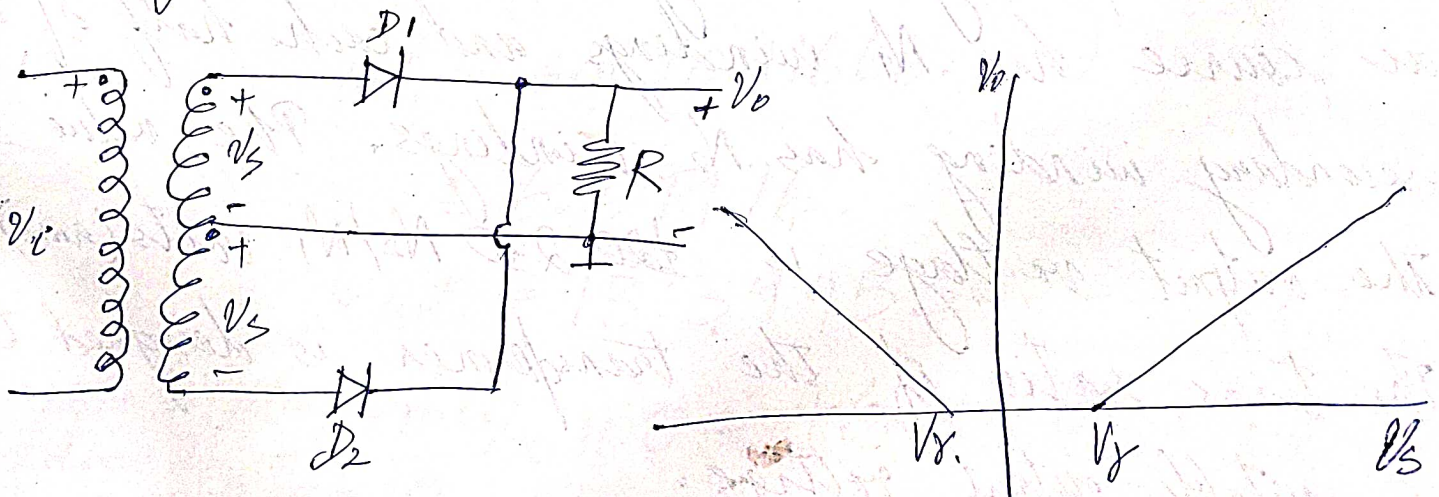
The fullwave rectifier inverts the negative portions of the sine wave so that an unipolar output signal is generated during both halves of the input sinusoid. One example of a full wave rectifier circuit appears in figure below. The input to the rectifier consists of a power transformer, in which the input is normally a 230V, 50 Hz signal and the two outputs are from a center-tapped secondary winding that provides equal voltages V_s with the polarities shown. When the input line voltage is positive, both output signal voltages V_s are also positive.

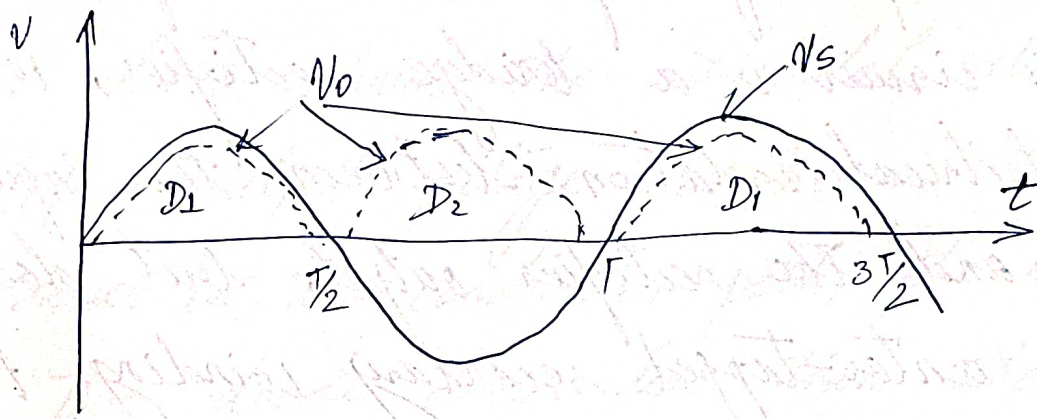
The primary winding connected to the 120V ac source has N_1 windings and each half of the secondary winding has N_2 windings. The value of the output voltage is ~~120~~ 230 N_2/N_1 volts (rms). The turns ratio of the transformer is designed to a suitable output voltage.

~~The input~~ The input power transformer also provides electrical isolation between the power line circuit

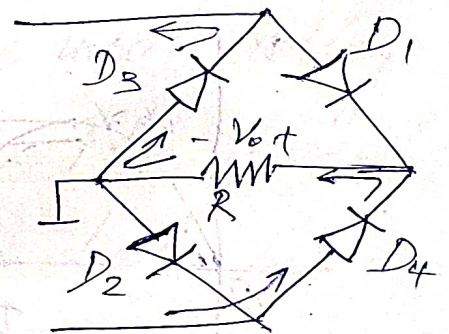
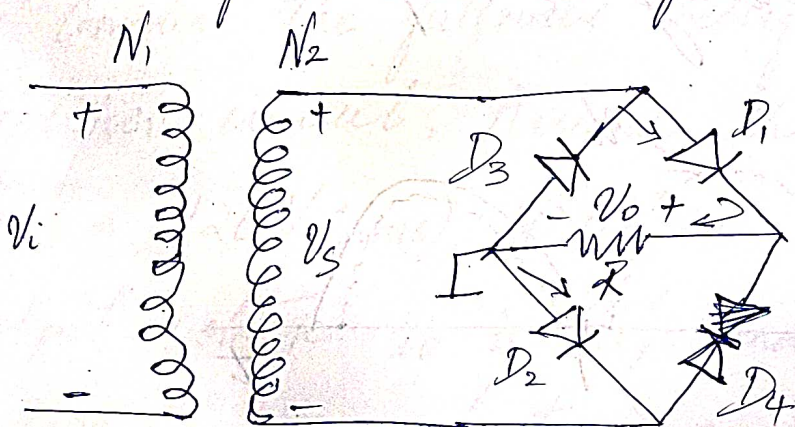
and the electronic circuit to be biased by the rectifier circuit. This isolation reduces the risk of electric shock.

During the positive half of the input voltage cycle both output voltages V_s are positive; therefore diode D_1 is forward biased and diode D_2 is reverse biased and off. The current through D_1 and the output resistance produce a positive output voltage. During the negative half cycle D_1 is out off and D_2 is forward biased or "on" and the current through the output resistance again produces a positive output voltage. If we assume that the forward diode resistance of each diode is small and negligible we obtain the voltage transfer characteristics as shown.





For a sinusoidal input voltage, we can determine the output voltage vs time by using the voltage transfer curve shown above. When $v_s > V_\gamma$, D_1 is on and the output voltage is $v_o = v_s - V_\gamma$. When v_s is negative, then for $v_s < -V_\gamma$ or $-v_s > V_\gamma$, D_2 is on and the output voltage $v_o = -v_s - V_\gamma$. The corresponding input and output voltage signals are shown ~~in~~ above. Since the rectified voltage occurs during the positive and negative cycles of this input signal, this circuit is called a full-wave rectifier.



Another example of a full wave rectifier is shown above. This circuit is a bridge rectifier, which still provides electrical isolation between the input ac powerline and the rectifier output, but does not require a center-tapped secondary winding. However it does use four diodes, compared to only 2 in the previous ~~input~~ circuit.

During the positive half of the input voltage cycle, v_s is positive D_1 and D_2 are forward biased, D_3 and D_4 are reverse biased, and the direction of the current is shown in figure (a). During the negative half of the input ~~cycle~~ voltage, v_s is negative and D_3 and D_4 are forward biased. The direction of the current is as shown in figure (b), produces the same output voltage polarity as before.

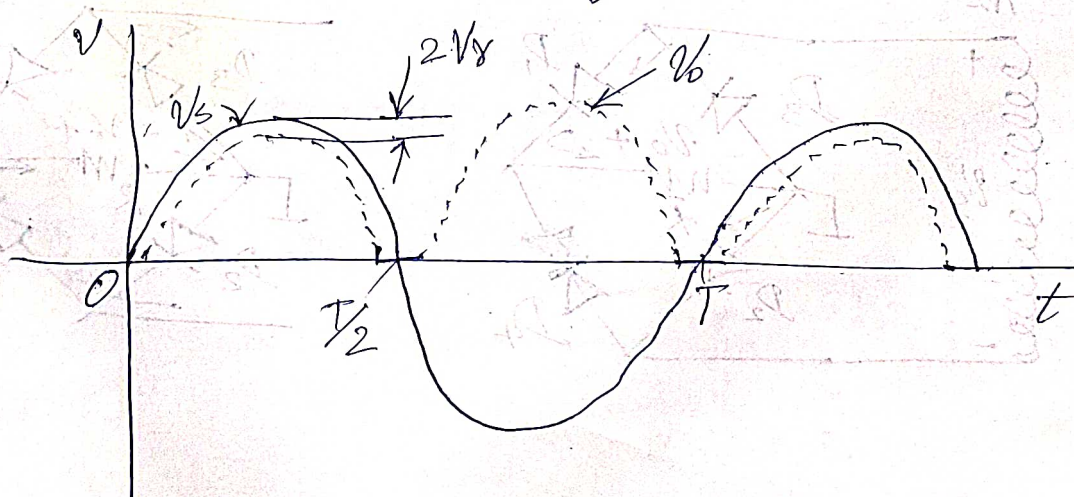


Figure above shows the sinusoidal voltage V_s and the rectified output voltage V_o . Because two diodes are in series in the conduction path, the magnitude of V_o is two diode drops less than the magnitude of V_s .

One difference to be noted in the bridge rectifier circuit and the full wave rectifier circuit is at ground potential, is the ground connection. Whereas the center tap of the secondary winding of the ^{bridge FWR} circuit is at ground potential, the secondary winding of the ~~full~~ bridge circuit is not directly grounded. One side of the load R is grounded but the secondary of the transformer is not.

Consider the full wave rectifier circuit and bridge rectifier circuit. Assume that the input voltage is from a $120V$ (rms), 60 Hz ac source. The desired peak output voltage V_o is $9V$, and the diode cut-in voltage is assumed to be $V_s = 0.7V$

For the center-tapped transformer circuit, a peak voltage of $V_o(\text{max}) = 9V$ means that the peak value of $V_s = V_o(\text{max}) + V_r$

$$= 9 + 0.7 = 9.7V$$

For a sinusoidal signal, this produces an rms value of

$$V_{s,\text{rms}} = \frac{9.7}{\sqrt{2}} = 6.86V$$

The turns ratio of primary to each secondary winding must then be

$$\frac{N_1}{N_2} = \frac{120}{6.86} \approx 17.5$$

For the bridge circuit shown in figure a peak voltage of $V_o(\text{max}) = 9V$ means that the peak value of V_s is.

$$V_{s(\text{max})} = V_o(\text{max}) + 2V_r = 9 + 2 \times 0.7 = 10.4V$$

For a sinusoidal signal this produces an rms value of

$$V_{s(\text{rms})} = \frac{10.4}{\sqrt{2}} = 7.35V$$

The turns ratio should then be

$$\frac{N_1}{N_2} = \frac{120}{7.35} \approx 16.3$$

For the center-tapped rectifier, the peak inverse voltage of the diode is

$$\begin{aligned} PIV = V_{R(max)} &= 2V_{s(max)} - V_f \\ &= 2(9.7) - 0.7 = 18.7V \end{aligned}$$

For the bridge rectifier the peak inverse voltage of the diode is

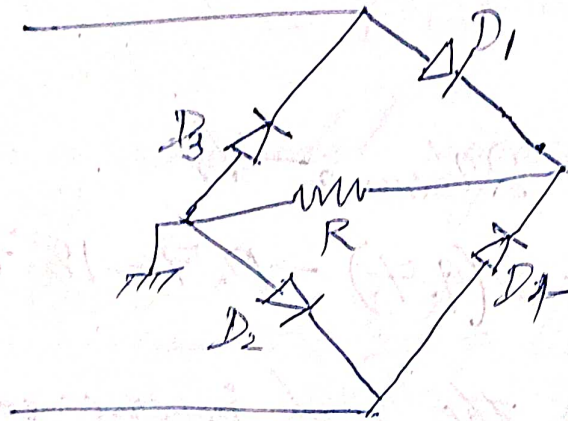
$$\begin{aligned} PIV = V_{R(max)} &= V_{s(max)} - V_f = 10.4 - 0.7 \\ &= 9.7V. \end{aligned}$$

Comment: These calculations demonstrate the advantage of the bridge rectifier over the center-tapped transformer circuit. First, only half as many turns are required for the secondary winding in the bridge rectifier. This is true because only half of the secondary winding of the center tapped transformer is utilized at any one time. Second for the bridge circuit, the peak inverse voltage

that any diode must sustain without breakdown is only half that of the center-tapped transformer circuit.

62.047
117.982

Consider the bridge circuit shown in figure with an input voltage



$V_s = V_m \sin(\omega t)$. Assume a diode cut-in voltage of $V_r = 0.7V$. Determine the fraction (percent) of time that the diode D_1 is

conducting for peak sinusoidal voltages of a) $V_m = 12V$ and b) $V_m = 4V$

$$a) 12 \sin(\omega t_1) = 2V_r$$

$$\sin(\omega t_1) = \frac{2V_r}{12} = \frac{V_r}{6} = \frac{0.7}{6} = 0.11666 \dots$$

$$\omega t_1 = \sin^{-1}(0.11666 \dots)$$

$$= 6.69976 \dots$$

$$2 \times \omega t_1 = 13.39953 \dots$$

$$\% \text{ of time } D_1 \text{ is conducting} = \frac{(180 - 2 \times \omega t_1)}{360} \times 100 = 46.27779 \%$$

$$b) \text{ Ans } 38.6 \%$$